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The relationship between rheological characteristics of gluten-free dough and the quality of biologically leavened bread

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ABSTRACT

The rheological characteristics of gluten-free doughs and their effect on the quality of biologically leavened bread were studied in amaranth, chickpea, corn, millet, quinoa and rice flour. The rheological characteristics (resistance to extension R, extensibility E, R/E modulus, extension area, stress at the moment of dough rupture) were obtained by uniaxial dough deformation. Specific loaf volume of laboratory prepared gluten-free breads was in significant positive correlation with dough resistance ($r = 0.86$), dough extensibility ($r = 0.98$) and peak stress at the moment of dough rupture ($r = 0.96$). Even if the correlation between R/E modulus and the characteristics of loaf quality were not significant, the breads with the highest specific loaf volume were prepared from flours with R/E closer to the wheat check sample (18 N·mm-1). The results showed, in general, good baking flours exhibited stronger resistance to extension and greater extensibility, but differences found were not directly related to the results of baking tests.

1. Introduction

The properties of wheat (*Triticum aestivum* L.) dough and the quality of biologically leavened wheat bread are mainly affected by the amount and quality of gluten proteins. During dough development, proteins form a gluten network with unique viscoelastic characteristics. Due to its strength and extensibility, leavening gas is retained in the dough and the typical foam structure is created. Although important in the bread-making process, the presence of gluten may be an issue for some people. In order to avoid the effects of entheropathy (celiac disease) a lifelong intolerance to the protein gliadin fraction, celiacs need a gluten-restrictive diet. The exclusion of gluten from bread production has a deteriorating effect on the quality of gluten-free dough and bread. Gluten-free dough viscosity is low, loaf crumb is hard, taste and aroma are insufficient, bread has low specific loaf volume, insufficient springiness, cohesiveness and resilience as well as short shelf life (Anton and Artfield, 2007; Gallagher et al., 2004). The quality of gluten-free bread is mainly influenced by the content and properties of polysaccharides, which increase dough foam stability by increasing viscosity, flocculation and coalescence, preventing effects on the dough aqueous phase and thus on the stability of the liquid film surrounding gas bubbles (Cosgrove, 2005; Dickinson, 2010).

The dough suitable for production of biologically leavened bread needs to have properties which enable them to stretch in response to the expansion of leavening gas. Dough films surrounding gas bubbles must have sufficient strength to prevent collapse, but at the same time, be capable of stretching (extensibility) without rupturing (Singh and MacRitchie, 2001). Dough properties can be measured using numerous rheological methods. The most often used instruments are farinograph, mixograph, extensograph, and alveograph (Dobraszczyk and Morgenstern, 2003). The Brabender farinograph is designed to record changes of dough consistency during kneading under standard conditions, i.e. throughout dynamic deformations. The test flour is placed into a bowl, and while being kneaded, water is added to reach 500 FU (farinographic units) dough consistency. This value was obtained empirically (Kuktaite et al., 2007) and is considered to be the optimal consistency of wheat dough used in the production of biologically leavened bread (Holas and Tipples, 1978). The Brabender extensograph records the dough resistance to stretching and the distance the dough stretches before it ruptures. These methods are usually criticised because of results interpretation in relative non-SI units, large sample requirements and the impossibility to define fundamental

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rheological parameters such as stress, strain, modulus or viscosity. The SMS/Kieffer Dough and Gluten Extensibility Rig is an alternative micro method (Kieffer et al., 1998). Despite the lower result correlation with the product quality, this method is used for testing dough rheological characteristics (e.g. Dunnewind et al., 2004; Tronsmo et al., 2003; Wang et al., 2004) and was used in this paper.

The rheological properties of wheat dough have been relatively well described, but significantly fewer papers focused on the rheological characteristics of gluten-free doughs have been published. The aim of this paper was to measure and compare the rheological characteristics of gluten-free doughs used for bread production and to specify the correlation between rheological characteristics and bread quality.

2. Material and methods

2.1. Gluten-free flours

Seven commercially milled gluten-free flours were used in the experiments. Amaranth flour was obtained from the company Josef Vince Jihlava, Czech Republic; chickpea, millet, and rice flours were obtained from company Natura Hustopeče, Czech Republic; corn flour from the Mlýn Herber, s.r.o. Opava Vávrovice, Czech Republic; quinoa flour was delivered by the company ASO Zdravý život Hranice, Czech Republic and buckwheat from the Pohankový mlýn Zdeněk Šmajstrla Frenštát p. R., Czech Republic. Commercially milled wheat flour was used as a check sample (Penam, a.s., Mlýn Kroměříž).

2.2. Dough extensographic properties

Flour (10.00 g) was mixed with 0.20 g of salt and water to prepare the dough of 500 FU consistency. Salt is one of the main dough components because it decreases dough stickiness, develops flavour and affects the brown colour of breads (Kent and Evers, 1994). Moreover, it affects the rheological characteristics of the dough (Farahnaky and Hill, 2007), so rheological characteristics are often tested on dough with salt addition.

The dough was made into thin rolls, put onto the lubricated surface of a Teflon mould and compressed with the lubricated top plate. Test pieces of dough were formed into 5 cm long pieces with trapezoidal cross-section (3 mm, 5 mm, 4 mm). The doughs were left resting for 40 min at 30 °C. Uniaxial extension tests were performed using a texture analyser TA.XT plus (Stable Micro Systems Ltd., UK) equipped with an SMS/Kieffer Dough and Gluten Extensibility Rig. The measurement conditions were: measure force in tension, pre-test speed 2.00 mm s^{-1}, test speed 3.00 mm s^{-1}, post-test speed 10.00 mm s^{-1}, distance 75 mm, trigger force 5 g. The force required to stretch the dough sample and the displacement of the hook were recorded as a function of time. Like the extensograph, the values of major importance were the peak force R (N), i.e. resistance to extension, and the distance at which this peak force occurs, which is the measurement of extensibility E (mm). Extension area A (N mm^{-1}) is the area under the curve which is proportional to the energy required to stretch the test piece to its rupture. It is related to the absolute levels of elastic and viscous components of the dough (Hou, 2010). The ratio number R/E (N mm^{-1}) was calculated. The values were reported as ratios relative to the wheat dough.

The force-displacement extensographic curves were recalculated into stress–strain curves as described by Dunnewind et al. (2004). The relative deformation in uniaxial extension of the dough test piece was described as the Hencky strain ε_H:

Table 1
Average values of dough characteristics.[a]

Flour	R (N)	A (N mm)	E (mm)	R/E 10^{-3} (N mm^{-1})
Amaranth	0.14 ± 0.03^{a}	0.7 ± 0.1^{ab}	8 ± 2^{b}	16 ± 3^{ab}
Buckwheat	0.12 ± 0.02^{a}	0.5 ± 0.1^{ab}	7 ± 2^{ab}	18 ± 4^{ab}
Chickpea	0.14 ± 0.03^{a}	1.0 ± 0.2^{b}	11 ± 2^{c}	12 ± 2^{a}
Corn	0.09 ± 0.02^{a}	0.1 ± 0.3^{a}	4 ± 1^{a}	27 ± 5^{c}
Millet	0.27 ± 0.05^{b}	1.2 ± 0.2^{b}	9 ± 2^{b}	31 ± 6^{cd}
Quinoa	0.28 ± 0.06^{b}	1.0 ± 0.2^{b}	8 ± 1^{b}	33 ± 7^{cd}
Rice	0.29 ± 0.06^{b}	1.5 ± 0.3^{bc}	9 ± 2^{b}	34 ± 7^{d}
Wheat	0.55 ± 0.09^{c}	11.4 ± 0.9^{d}	30 ± 5^{e}	18 ± 3^{ab}

R: dough resistance to extension; A: extension area; E: dough extensibility; R/E: ratio number.
[a] Values in one column with different letters are significantly different $p < 0.01$.

$$\varepsilon_H = \ln(l_t/l_0) \tag{1}$$

where l_0 is the initial length of the sample and l_t is the length at time t. The strain rate is not constant in the Kieffer test and can be written as:

$$\dot{\varepsilon} = \mathrm{d}\varepsilon_H/\mathrm{d}t \tag{2}$$

The force acting on the dough F_d can be calculated from measured force F_m:

$$F_d = F_m l_t/4 \cdot (y_t + y_0) \tag{3}$$

in which y_t is the displacement of the hook from the point at which the actual extension starts. The stress σ can be calculated:

$$\sigma = F_d \cdot l_t/V. \tag{4}$$

The stress–strain curves can be characterised by peak stress σ_M and peak strain ε_{HM} at which the sample ruptures.

2.3. Bread preparation

The batter was prepared in the mixer (Spar Food Machinery MFG, Co., Ltd. Taiwan), mixing 300 g of flour, water according to 500 FU farinograph waterabsorption, 1.5% (w/w) of salt, 1.86% (w/w) of saccharose and 0.005% (w/w) of ascorbic acid for 3.0 min. Yeast (1.8% w/w) was added and the batter was further mixed for 6.0 min. The amount of dry yeast, salt, saccharose and ascorbic acid was related to 300 g of flour. The batter was scaled into three bread pans and placed into a proofer for 20 min at 30 °C and 85% relative air humidity. The loaves were baked for 20 min at 180 ± 5 °C in a steamy oven. After 20 ± 4 h from baking, the loaf volume and crumb texture characteristics were analysed.

Loaf volume was measured using plastic granulate of rape-seed size. Loaf specific volume was obtained by dividing bread volume by bread weight. The bread crumb characteristics were measured on samples of 40 mm diameter and 10 mm height obtained from the centre of each loaf. A compression test was carried out using a texture analyser TA.XT plus (Stable Micro Systems Ltd., UK). Compression was achieved through a 36.0 mm diameter cylinder probe P/36R. Instrument settings were: pre-test speed 1.00 mm s^{-1}, test speed 5.00 mm s^{-1}, post-test speed 5.00 mm s^{-1}, strain required to compress the bread slice to 60% of the initial height, trigger force 5.0 g. The following texture parameters were determined by ExponentLite software: crumb hardness, stickiness and cohesiveness.

2.4. Statistical analysis

Data were statistically analysed using analysis of variance ANOVA. The differences were tested on α = 0.01 and 0.05 levels